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REDUCED SET POINT TEMPERATURE IN EXERCISING DOG

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FOREWORD

This study was initiated by the Biothermal Branch of the Physiology Division, Biomedical Laboratory, 6570th Aerospace Medical Research Laboratories. The research was conducted by the John B. Pierce Foundation Laboratory of New Haven, Connecticut, under Contract AF 33(657)-7603. Dr. Harold T. Hammel, Head of the Physiology Division, was the responsible investigator for the John B. Pierce Foundation Laboratory. The work was performed in support of Project No. 7222, "Biophysics of Flight," Task No. 722204 "Human Thermal Stress." Dr. A. T. Kissen, Biothermal Branch, was the contract monitor for 6570th Aerospace Medical Research Laboratories. The research was started in October 1961 and completed in May 1963. This investigation is also a dissertation presented to the faculty of the Graduate School of the University of Pennsylvania in partial fulfillment of the requirement for the Ph.D. degree.

The experiments reported herein were conducted according to the "Principles of Laboratory Animal Care" established by the National Society for Medical Research.

ABSTRACT

Experiments were performed on dogs to test the hypothesis of an elevated set point temperature in exercise. Measurements of rectal, hypothalamic, and skin temperatures and respiratory evaporative heat loss were made on dogs at rest and during exercise on a level treadmill at 4 mph. Local hypothalamic heating and cooling during exercise, using surgically implanted thermodes, were performed on two dogs to confirm the temperature sensitivity of the hypothalamus of the exercising dog. Comparisons of evaporative heat loss during rest and exercise revealed much greater loss during exercise than at rest at the same hypothalamic temperatures. In experiments at low ambient temperatures, between 10°C and 17°C, internal body temperatures were often the same or lower during exercise than during the preceding rest period, although panting and vasodilatation were observed during exercise in contrast to shivering and vasoconstriction during the rest period. These observations lead to the conclusion that the set point temperature in trained, exercising dogs is lowered from the resting level.

PUBLICATION REVIEW

This technical documentary report is approved.

EVAN R. GOLTRA
Lt. Colonel, USAF, MC
Chief, Biophysics Laboratory

INTRODUCTION

Due to the constancy of the internal temperature of homolothermic animals and the regulatory responses utilized to maintain this temperature, it has become generally accepted that there is a set point temperature against which the body temperature is regulated. This is considered by some (ref. 5) to be a fixed point under many conditions of internal and external thermal stress while others (ref. 7, 11) propose a more variable set temperature dependent on a variety of influences from outside the regulating center of the hypothalamus. At present the temperature rise in fever is the best established example of set point shift (ref. 1, 6), although the well regulated temperature changes seen, for example, in sleep and exercise are believed by some to represent set point shifts.

The closely regulated rise in temperature observed during exercise was first demonstrated clearly in humans by Nielsen (ref. 15), who showed that if the work rate is constant, the rectal temperature rises to the same value within a wide range of ambient temperatures. From this well confirmed observation (ref. 6, 16, 19), he surmised that what was occurring was an elevation of the set point temperature. Although this interpretation was well received, it has never been definitely proven from a regulatory point of view.

Hammel et al (ref. 11), in their hypothesis of an adjustable set point, emphasize that in all set point shifts, the thermoregulatory drive is the difference between the hypothalamic temperature and the set temperature; that is, the load error. Afferent inputs from thermal changes in the periphery or other possible central receptors are only effective insofar as they modify the set point. On this basis then it is appropriate to question whether an increased set point temperature in exercise permits sufficient load error to drive the required heat dissipation.

The experiments described in this report were designed to test, in the dog, the hypothesis of an elevated set point temperature in exercise by correlating the respiratory evaporative heat loss during rest and exercise with the corresponding hypothalamic temperature.

METHODS

Six stainless steel thermodes were surgically implanted in an array bracketing the anterior hypothalamus of four healthy mongrel dogs (ref. 10). These thermodes could be perfused with water for hypothalamic temperature displacement. A mid-line re-entry tube was implanted to allow insertion of a thermocouple for hypothalamic temperature recording. The dogs were trained to run on a level treadmill at 4 miles per hour while wearing a ventilated muzzle-type mask. Room air was drawn through the mask and then passed through a humidity sensing element and a gas meter. Experiments were conducted in a climatic chamber allowing close regulation of temperature and humidity. Room air humidity was also measured with a hygrometer.

Three skin temperatures, rectal temperature, and hypothalamic temperature were measured using copper-constantan thermocouples and recorded continuously along with humidity and room air on a recording potentiometer.

Evaporative heat loss determinations were limited to intervals of 10 to 30 minutes in which the dog was close to being in thermal equilibrium. The hygrometer responded to rapidly increasing and steady state humidity in about a minute but had a full response lag of about 5 minutes in response to rapidly falling humidity. Observations in which there was a rapidly falling rate of evaporative heat loss were therefore considered significant qualitatively but not quantitatively. The determination was calibrated by measuring the weight loss from an evaporating surface at both rest and exercise flow rates and was found to be accurate to 5%.

The method of locally heating and cooling the hypothalamus has been described for resting dogs (ref. 11).

RESULTS

1. Hypothalamic temperature changes during exercise

Hypothalamic and rectal temperatures were recorded on three dogs at rest and exercise at ambient temperatures between 10°C and 31°C. The relationship between these two internal temperatures was noted during both states. At rest, the relationship varied from dog to dog. Dog B always had a higher hypothalamic temperature; Dog C always had a higher rectal temperature; while Dog D was intermediate. In previous reports (ref. 9), a higher hypothalamic temperature is most common, although variations are not unusual.

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During exercise, on the other hand, rectal temperature in these three dogs exceeded hypothalamic temperature in all cases. The mean difference between the two temperatures was 0.5°C.

The internal temperature rise during exercise showed some dependency on the ambient temperature as illustrated in Figure 1 for both hypothalamic and rectal temperatures. All the temperatures depicted were the steady state levels achieved after at least 20 minutes of running. This dependency on ambient temperature, although not generally seen in human studies, was recently reported by Schaff and Vogt (ref. 18).
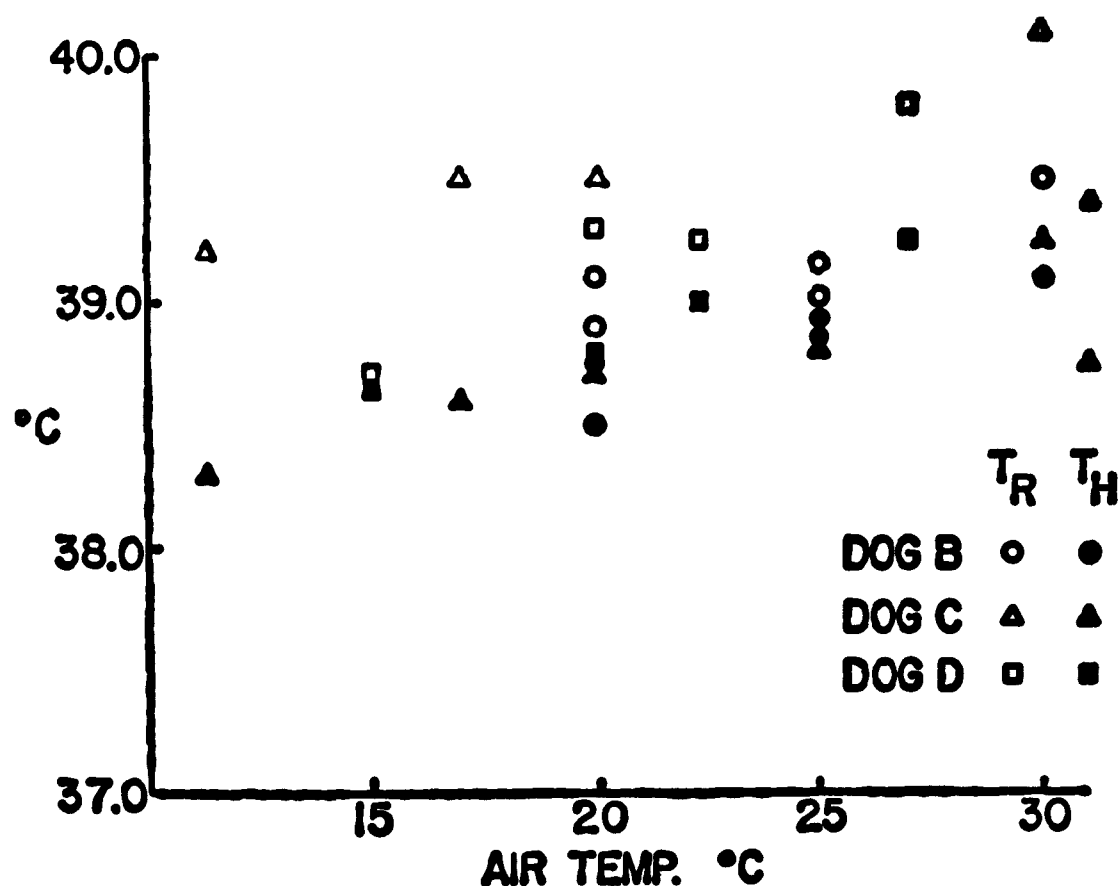

Fig. 1   Steady state rectal (T_R) and hypothalamic (T_H) temperatures for three dogs during exercise plotted against ambient temperature.

2. Hypothalamic temperature displacement

Local hypothalamic heating and cooling by perfusing water in the implanted thermodes was performed on Dogs A and D during exercise. Figure 2 shows data from an experiment in which a dog was cooled.
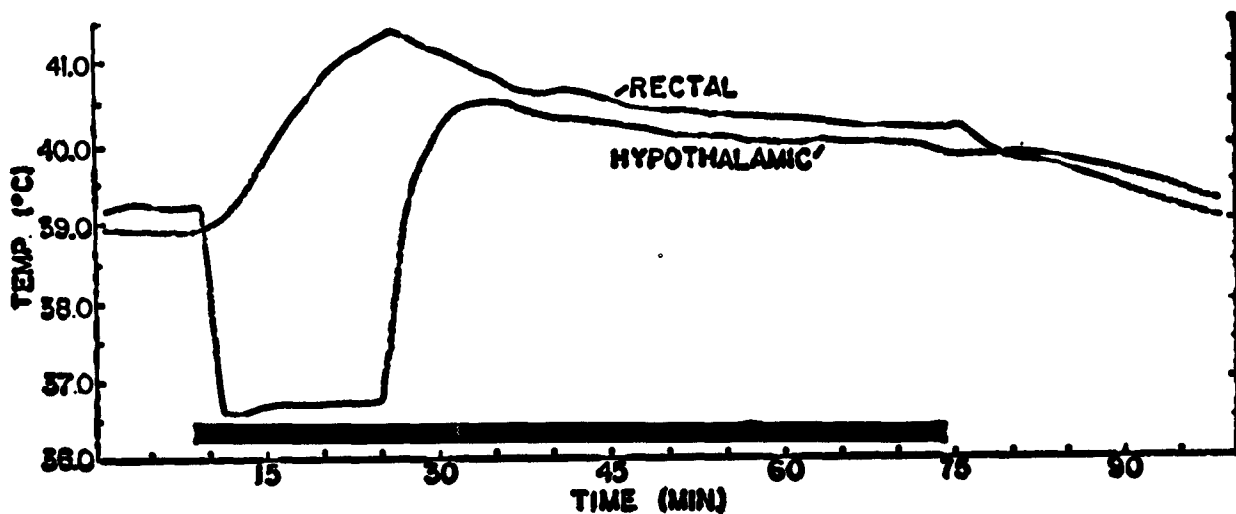

Fig. 2 Hypothalamic Cooling in an Exercising Dog (Dog A) at 22°C air temperature. Hatched line indicates exercise. Cooling began at 10 minutes and ended at 25 minutes.

Figure 3 is a direct tracing of an experiment on Dog D in which both heating and cooling were performed. It can be seen that heating promoted
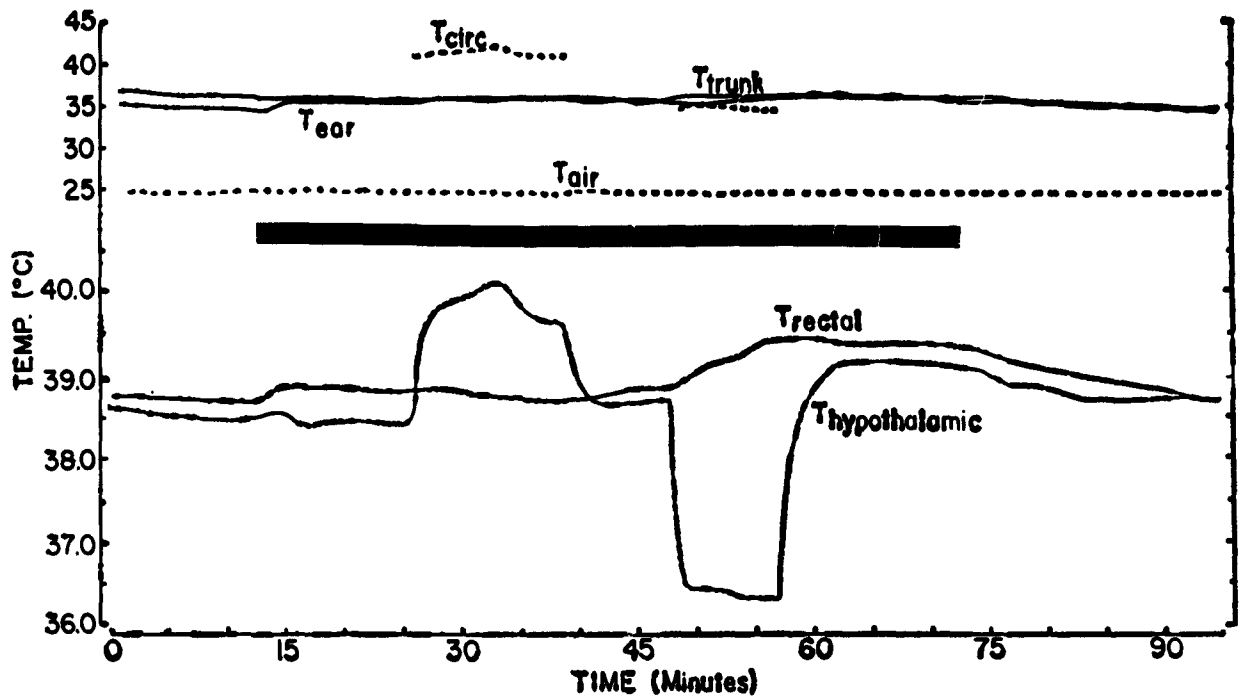
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heat dissipation to a slight degree whereas cooling caused heat retention
in a pronounced fashion. At the onset of heating, a transient increase in
respiratory evaporative heat loss occurred while at the onset of cooling a
transient decrease was observed. During the balance of the heating or
cooling period the evaporation approached the preperfusion levels.

3. Respiratory evaporative heat loss

Experiments were performed on Dogs B, C, and D in which respiratory
evaporative heat loss, hypothalamic temperature, rectal temperature, and
three skin temperatures were recorded during rest and exercise at 4 miles per
hour on a level treadmill at several ambient temperatures between 10°C and

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30°C. Dog A was sacrificed prior to the initiation of this series of experiments. Integrated evaporative heat loss determinations, plotted against corresponding hypothalamic temperatures for both rest and exercise, are shown in Figures 4a, 4b, and 4c. Data from each dog is plotted separately.
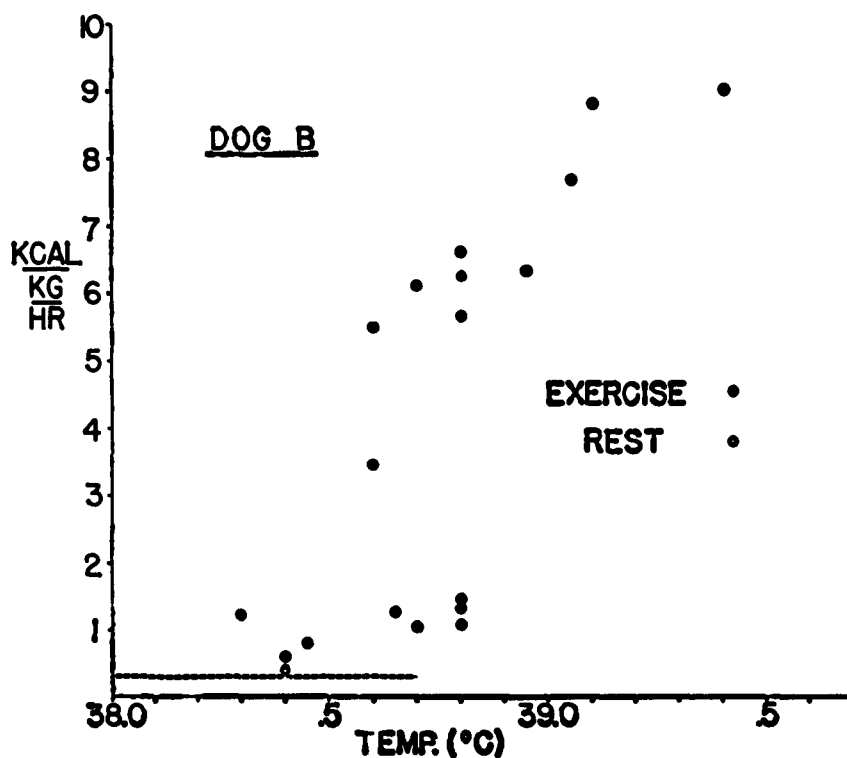

Fig. 4a   Steady state respiratory evaporative heat loss measurements on Dog B during rest and exercise plotted against hypothalamic temperature. Dotted line represents insensible evaporative heat loss (ref. 13).
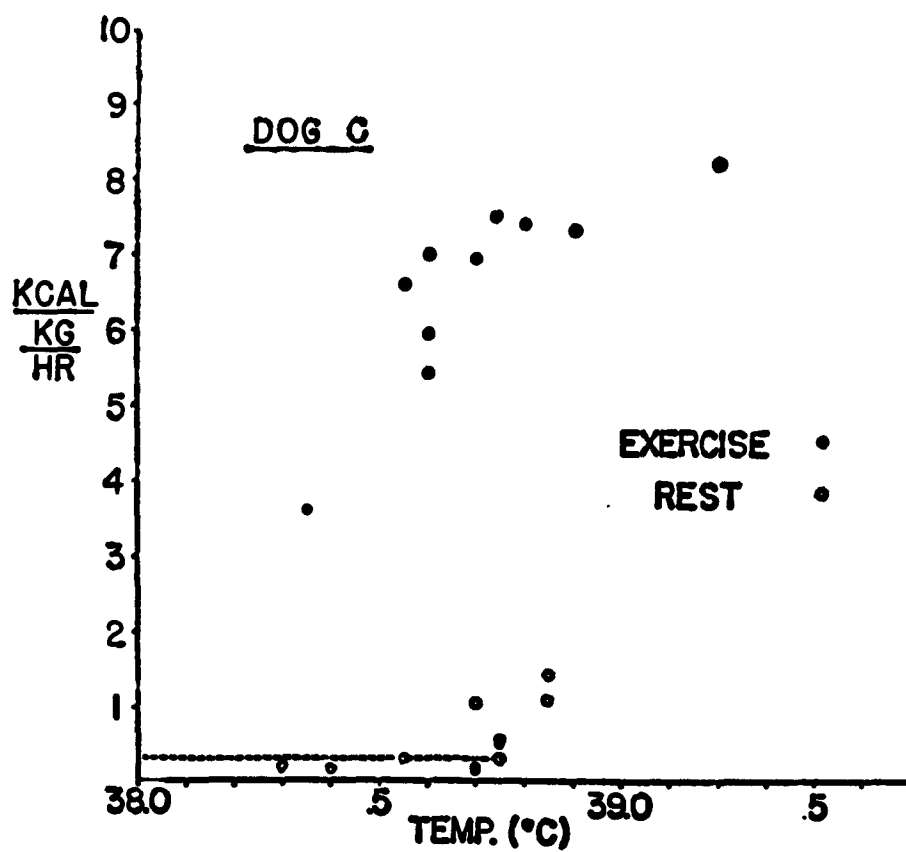
Fig. 4b Steady state evaporative heat loss measurements on Dog C during rest and exercise plotted against hypothalamic temperature.
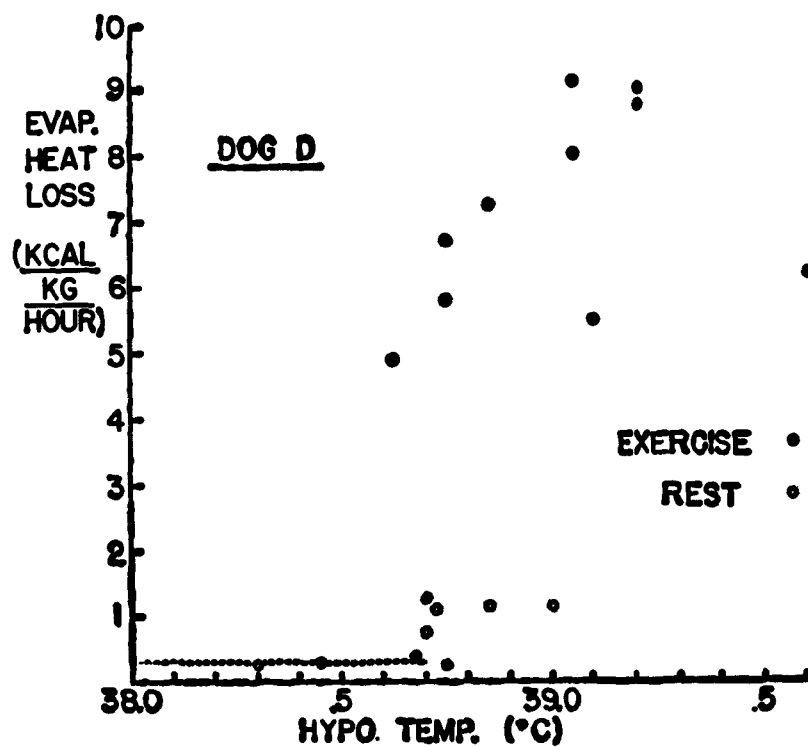
Fig. 4c   Steady state evaporative heat loss measurements
           on Dog D during rest and exercise plotted against
           hypothalamic temperature.

On Dog D, two exercise points are shown which lie considerably to the right of the others. These values were obtained from the dog after a month of inactivity. The remaining experiments were postponed 10 days during which time the dog was exercised daily on the treadmill.

Several conclusions may be drawn from these graphs concerning the regulation of respiratory heat loss during rest and exercise. (a) In resting Dogs C and D, there was insensible respiratory heat loss for hypothalamic temperatures up to about $38.7°C$. Above this temperature there was active panting. In resting Dog B, there was also active respiratory heat loss (panting) at $38.7°C$ and higher, but there was somewhat more than the insensible amount of respiratory heat loss down to $38.3°C$. (b) In all exercising dogs, there was a several fold increase in respiratory heat loss over the same range of hypothalamic temperatures as in the resting dogs. (c) The respiratory heat loss increased with increasing hypothalamic temperature in the exercising dog. (d) The exercise points lie on a line shifted to the left of the resting points. These results are inconsistent with hypothesis of an elevated set point which would shift the line to the right, but is suggestive of a decrease in the set point temperature of about $0.8°C$ for the level of exercise maintained in these experiments.

There is also the possibility of a change in the proportionality constant, or sensitivity, of the regulating mechanism, represented in Figures 4a, 4b, and 4c by the slope of the curve of the experimental points.

Hammel et al (ref. 12), on the basis of calorimetric data on the resting dog, found the proportionality constant to be 3.8 Kcal/Kg/Hr/$°C$ rectal temperature. When least square lines are drawn through the exercise points of these three dogs, proportionality constants, or slopes, of 5.7, 4.9, and 6.0 Kcal/Kg/Hr/$°C$ hypothalamic temperatures respectively are obtained. It would appear likely, therefore, that there is some increase in the gain of the system, but if this were the only change taking place, the two lines for rest and exercise should intercept the baseline at the same hypothalamic temperature, which they do not appear to do. In Figure 5, the data from the three dogs are combined. The shift to the left is quite easily seen in this figure.
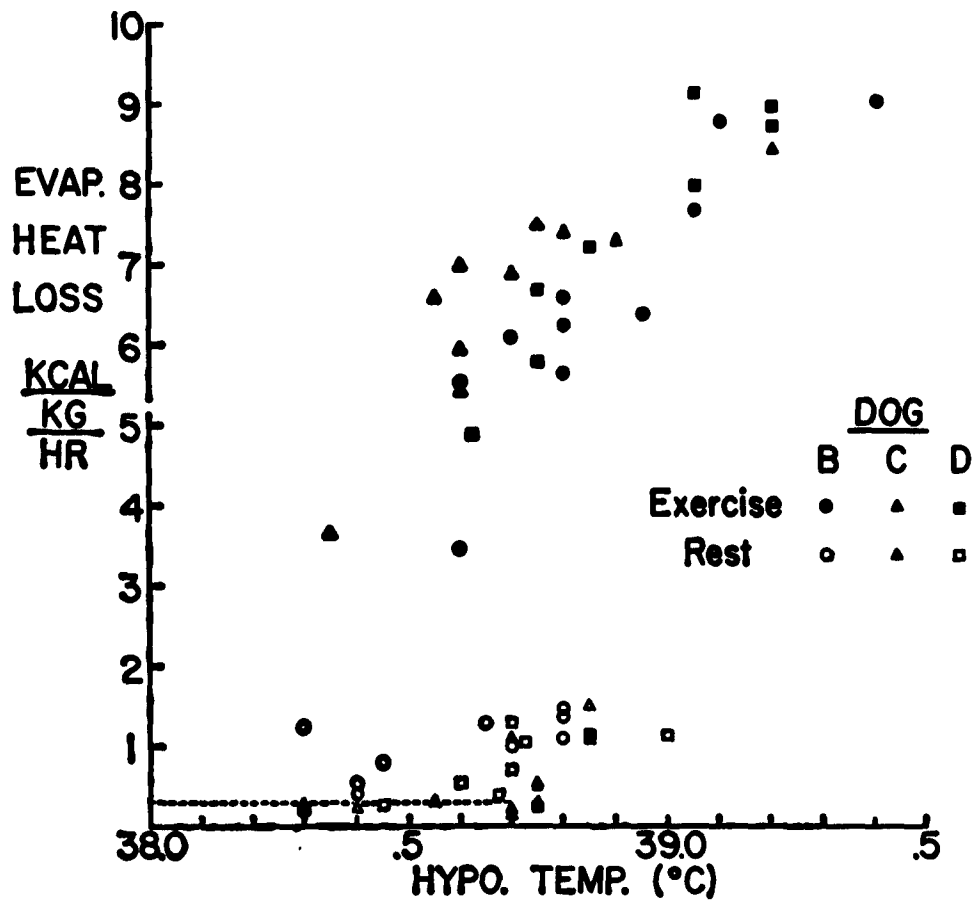
Fig. 5   Combined data from Figures 4a, 4b, and 4c. Note
shift to the left of the resting line for evaporative
heat loss measurements during exercise.

In Figure 6 is shown an experiment at an air temperature of 11°C in
which Dog C was actively shivering during the rest period, indicating that
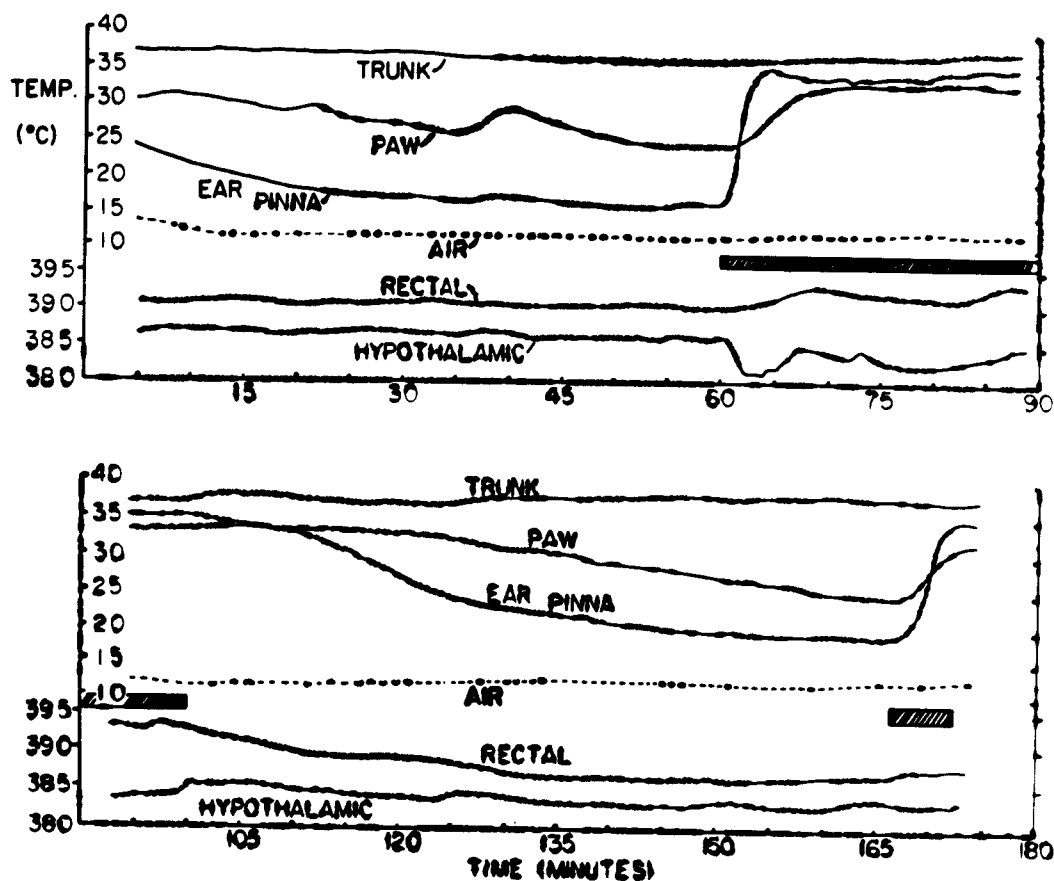his hypothalamic temperature was below the set point.

Fig. 6   Experiment on Dog C in which the Hypothalamic
Temperature Fell during Exercise (hatched bar).
Evaporative heat loss during exercise was 3.6
Kcal/Kg/Hr and during rest 0.3 Kcal/Kg/Hr.

At 60 minutes (upper tracing), the dog began to exercise and its
hypothalamic temperature fell transiently before levelling off at 38.3°C,
lower by 0.3°C than the resting level. At 166 minutes, a second period
of running was begun and the resting hypothalamic temperature of 38.3°C
was unchanged during 8 minutes of running. In each case, however, the ear
pinna and paw temperatures were observed to begin rising to fully dilated
levels within 1 or 2 minutes after running began and a similar increase was
seen in the evaporative heat loss (not shown). If either an elevated set
point or an increased gain by itself are postulated, the responses in each
of these transitions from rest to exercise should have been an exaggeration
of the resting response (heat conservation) and not a shift to heat loss
responses.

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In the experiment just discussed, it may be observed that both the skin and rectal temperatures were rising early in the exercise period and may have been influencing the response. In Figure 7 is shown an experiment on Dog D at an air temperature of 15°C, also well below the dog's neutral temperature. In this experiment the steady state exercise level of the rectal temperature (38.75°C) was lower than that measured during rest (39.1°C) and the skin temperatures were nearly unchanged. The hypothalamic temperature, except for a transient increase at the start of exercise, was also unchanged. Despite this apparent lack of thermal drive, the respiratory evaporative heat loss increased five-fold.
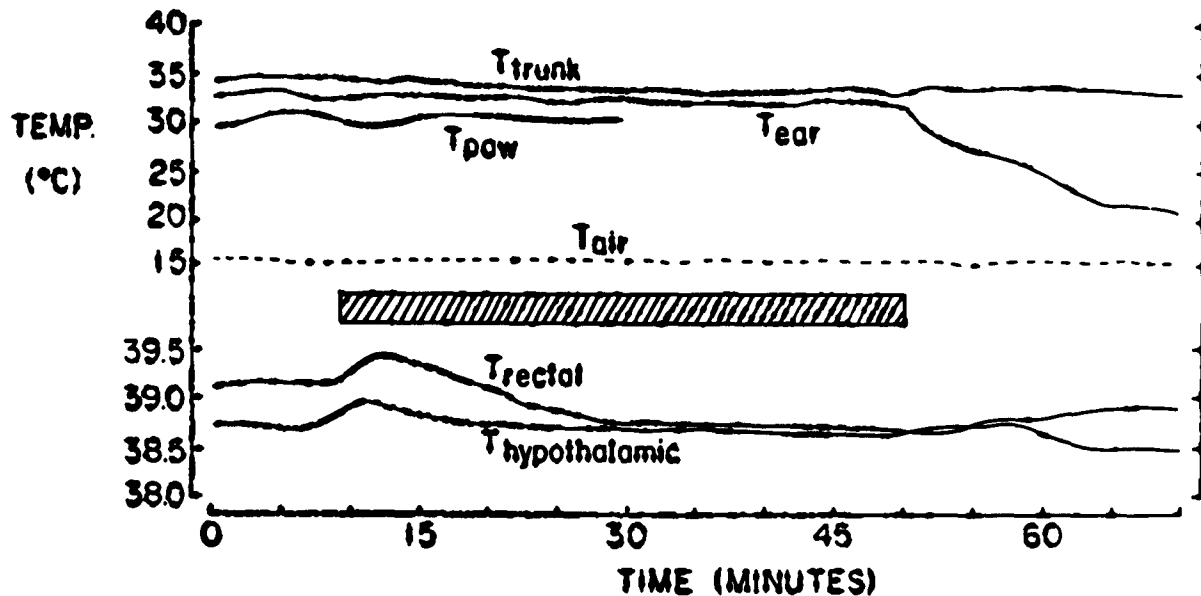

Fig. 7   Experiment on Dog D in which hypothalamic and skin temperatures remained unchanged and rectal temperature fell during exercise (hatched bar). However, the evaporative heat loss during exercise was 4.9 Kcal/Kg/Hr as compared to 0.55 Kcal/Kg/Hr during the rest period.

DISCUSSION

The experiments just described provide quantitative evidence that the set point temperature in exercising dogs is not elevated but is, in fact, decreased. This conclusion is based on the assumption that the preponderant drive in temperature regulation is represented by the difference between the hypothalamic temperature and the set temperature. Since other factors besides exercise may change the set point, it is likely that there was not a constant set point shift in all the experiments described, however, it is certain that in all cases the set point did fall. Hammel et al (ref. 11) present evidence that a rising core and/or skin temperature tend to lower the set point, a condition that prevails in most cases of exercise. In the ⌐ ⌐ experiment described in which this did not occur, (Fig. 7), the set point apparently shifted downward anyway demonstrating the overriding effect of the shift due to exercise alone. An alternative interpretation possible from this data other than a lowered set point is the existence of an extremely powerful regulatory drive from somewhere in the body, such as the muscles, which is capable of dominating the hypothalamic drive. However, there is no evidence to date for such a powerful extra-hypothalamic drive.

The temperature of the hypothalamus was employed because of the critical role that this brain area is known to play in temperature regulation. Its importance during exercise was confirmed by the experiments in which the hypothalamus was locally heated and cooled. The comparison of steady state hypothalamic and rectal temperatures in exercise reveals a fairly consistent relationship in which the rectal temperature is nearly always above the hypothalamic temperature by an average of 0.5°C. The rectal temperature of the dog, in contrast to man, changes at about the same rate as the hypothalamus and reaches equilibrium in about the same time. This lower thermal inertia is probably related to the difference in size of dog and man. A meaningful correlation can also be made between rectal temperature and respiratory evaporative heat loss in the exercising dog.

There is an evident advantage gained by the exercizing dog in a lowered as opposed to an elevated set point. Although extreme changes in body temperature in either direction can have damaging effects, overheating is considered the greater danger to homoiothermic animals due to the narrow margin separating the normal internal temperature from the 'thermal death point.' For this reason, according to Hardy (ref. 13), the major function of the thermoregulatory system is protection against overheating. During exercise, body temperatures generally rise, and, during extreme exertion, may even approach the upper limit of survival. It is to be expected, therefore, that the thermoregulatory response in exercise should be directed toward minimizing the temperature rise while still allowing sufficient rise to drive the heat loss mechanisms adequately. Under these circumstances the least advantageous response would be to raise the set point, since this would require the body temperature to rise higher to achieve the same load error than would be necessary if the set point were unchanged.

On the other hand, the presence of a lowered set point, with a probable increase in sensitivity to temperature change, provides the dog with a theoretically ideal system of regulation in exercise from the point of view of minimizing the temperature rise. Since the drop in set point in most cases does not eliminate the temperature rise, especially in the exercising muscles, the beneficial effects on muscular performance are still enjoyed but with less risk of overheating.

Extrapolation of the present findings in exercising dogs to exercising humans is not justified at the present time. In fact, there is some evidence that the set point may remain unchanged during exercise in man. First Benzinger (ref. 5) and more recently Belding and Hertig (ref. 4) have observed steady state sweating values during both rest and exercise to fall on a common line when plotted against tympanic membrane temperature. The intersection of this line with the temperature baseline represents the set point for sweating which would thus be the same for both rest and exercise. In contrast to these results, Minard and Copman (ref. 14) have measured greater sweating rates during exercise than during rest over the same range of internal temperatures. This observation could be interpreted as representing either an increase in the sensitivity or a decrease in the set point as a result of exercise.

There is also the possibility that training may have some influence on the set point change. In Figure 4c, there are two evaporative heat loss measurements made on Dog D following a month of inactivity. These points lie considerably to the right of the points obtained after physical training, and, in fact, appear to be on the same line as the resting points, suggesting no shift at all in set point. This is admittedly scanty evidence, but it may possibly have some bearing on the beneficial effects of training. A comparable change may well occur in acclimatization to heat in which higher sweat rates are possible at lower internal temperatures than in the unacclimatized condition (ref. 17). This is equivalent to a decrease in the set point.

The mechanism for shifting the set point in exercise is an open question. Certain authors (ref. 2, 3) have suggested that the elevated set point, as proposed by Nielsen, may be explained by nervous impulses arising from muscle or joint receptors acting on hypothalamic thermo-detectors. From the present study, we may conclude that whatever the influences associated with exercise are, their effect appears to be a lowering rather than an elevating of the temperature set point.

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